



US009182552B2

(12) **United States Patent**
Beausoleil et al.

(10) **Patent No.:** **US 9,182,552 B2**
(45) **Date of Patent:** **Nov. 10, 2015**

(54) **OPTICAL CONNECTIONS**

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(75) Inventors: **Raymond G. Beausoleil**, Redmond, WA (US); **David A. Fattal**, Mountain View, CA (US); **Marco Fiorentino**, Mountain View, CA (US); **Paul Kessler Rosenberg**, Sunnyvale, CA (US)

(73) Assignee: **Hewlett-Packard Development Company, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/357,841**

(22) PCT Filed: **Dec. 9, 2011**

(86) PCT No.: **PCT/US2011/064128**

§ 371 (c)(1),

(2), (4) Date: **May 13, 2014**

(65) **Prior Publication Data**

US 2014/0308006 A1 Oct. 16, 2014

(51) **Int. Cl.**

G02B 6/34 (2006.01)

G02B 6/28 (2006.01)

G02B 6/293 (2006.01)

G02B 6/38 (2006.01)

(52) **U.S. Cl.**

CPC **G02B 6/34** (2013.01); **G02B 6/29304** (2013.01); **G02B 6/3845** (2013.01); **G02B 6/3885** (2013.01); **Y10T 29/49826** (2015.01)

(58) **Field of Classification Search**

CPC **G02B 6/29304**

See application file for complete search history.

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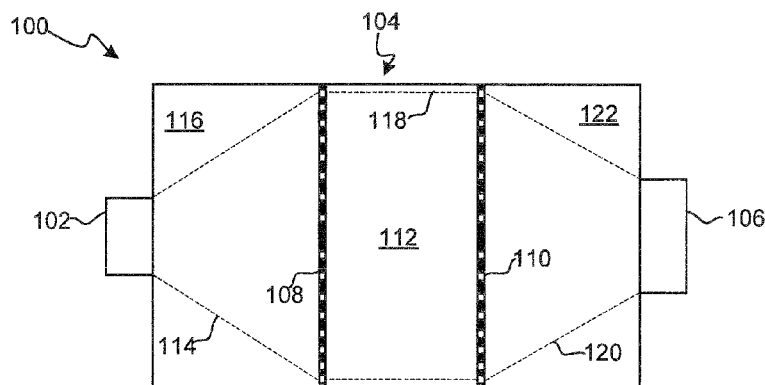
Primary Examiner — Jerry Rahlh

(74) *Attorney, Agent, or Firm* — Hewlett-Packard Patent Department

(57) **ABSTRACT**

Techniques related to optical devices are described herein. In an example, an optical device includes (a) an input optical channel and a corresponding output optical channel, and (b) an assembly of sub-wavelength grating layers aligned to optically couple the input optical channel to the output optical channel.

19 Claims, 11 Drawing Sheets



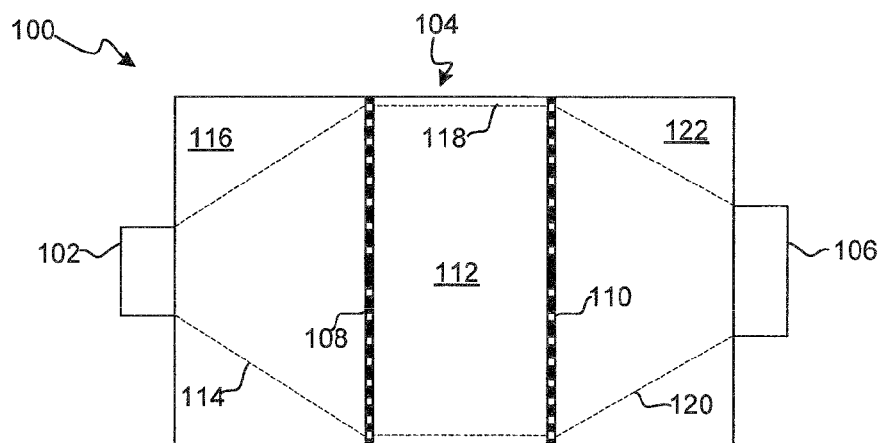


FIG. 1

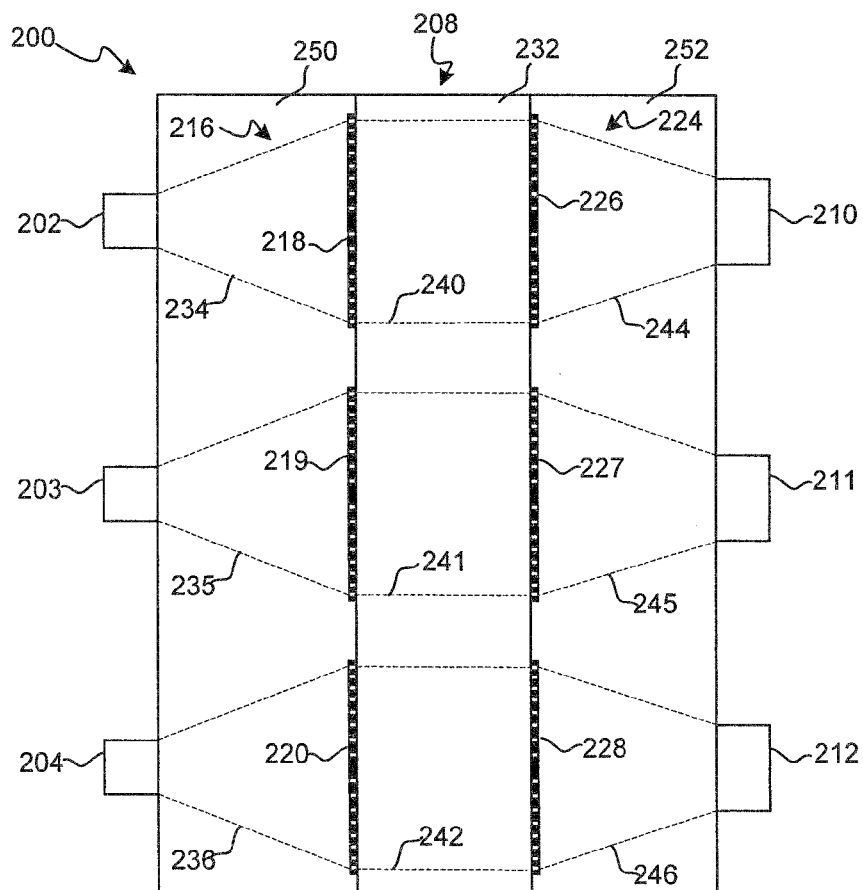


FIG. 2

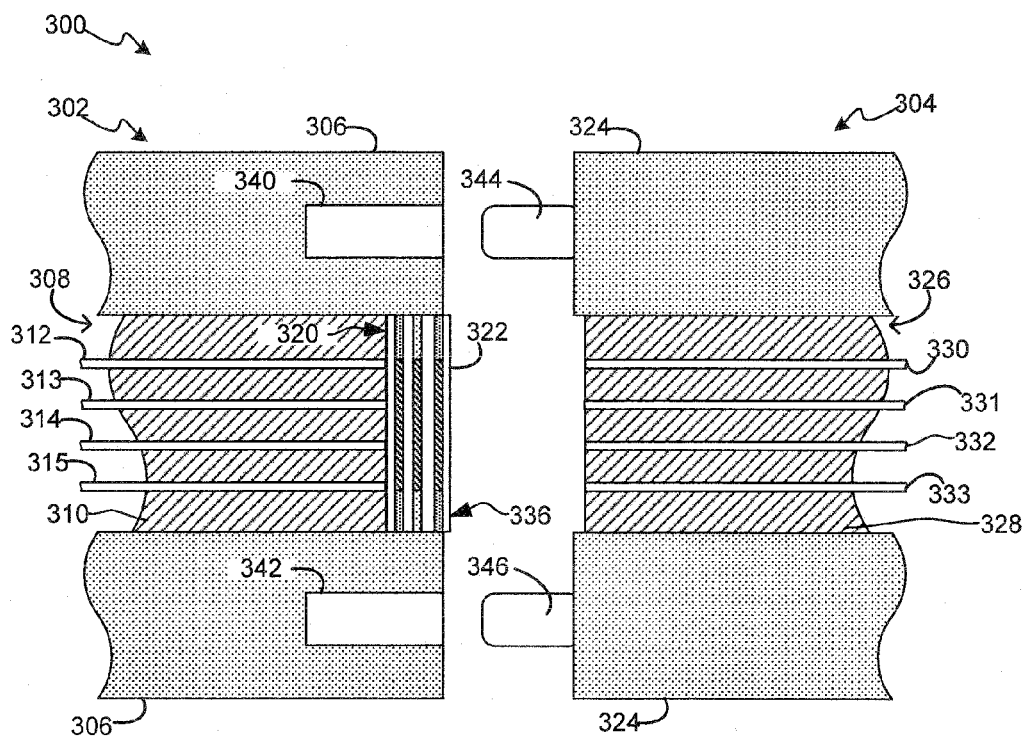


FIG. 3A

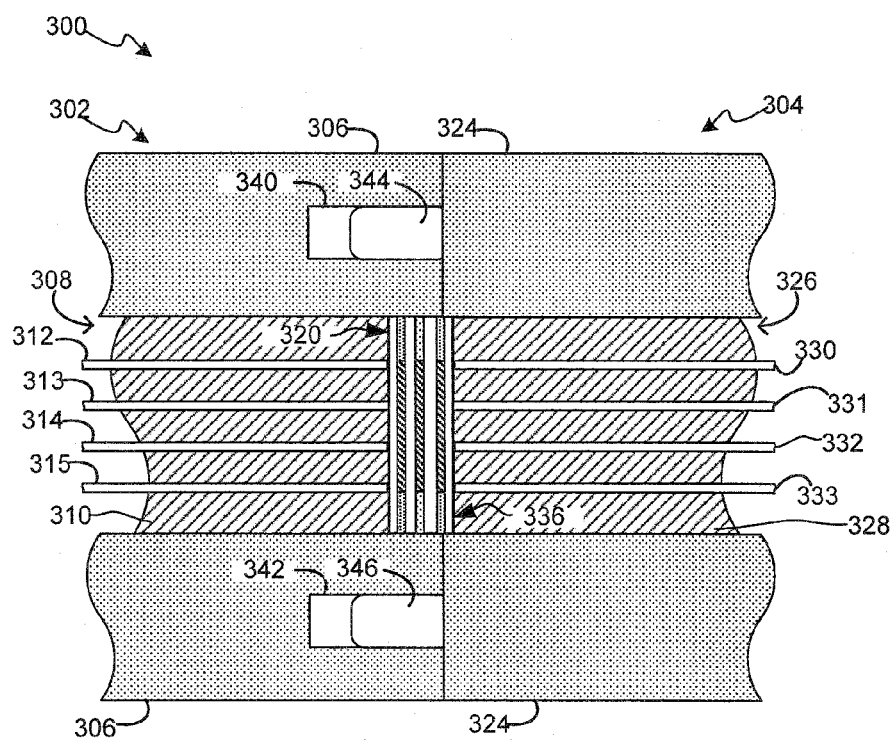


FIG. 3B

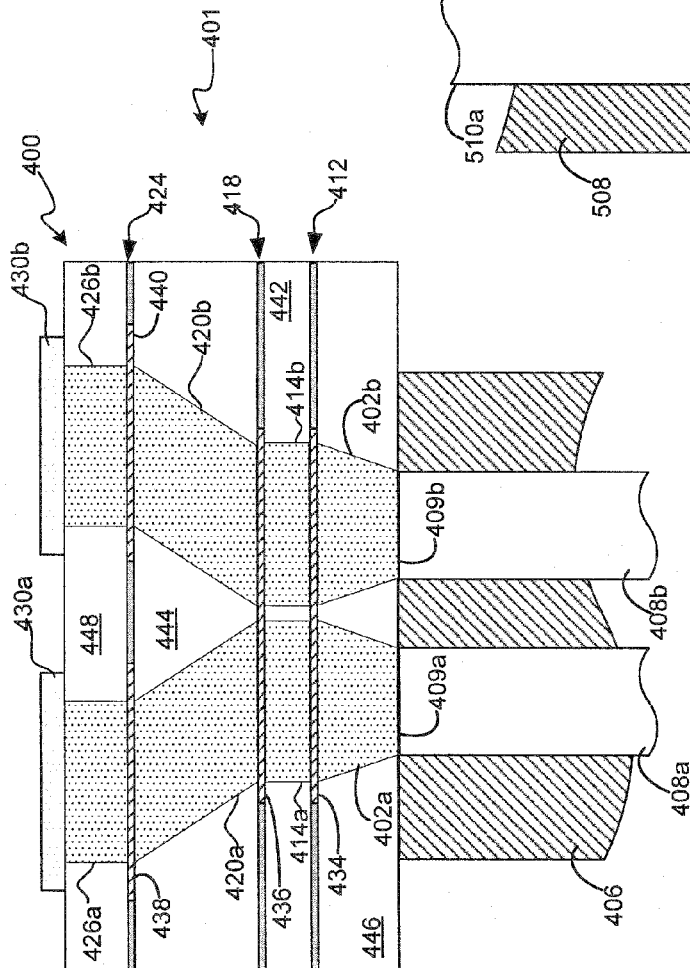


FIG. 5

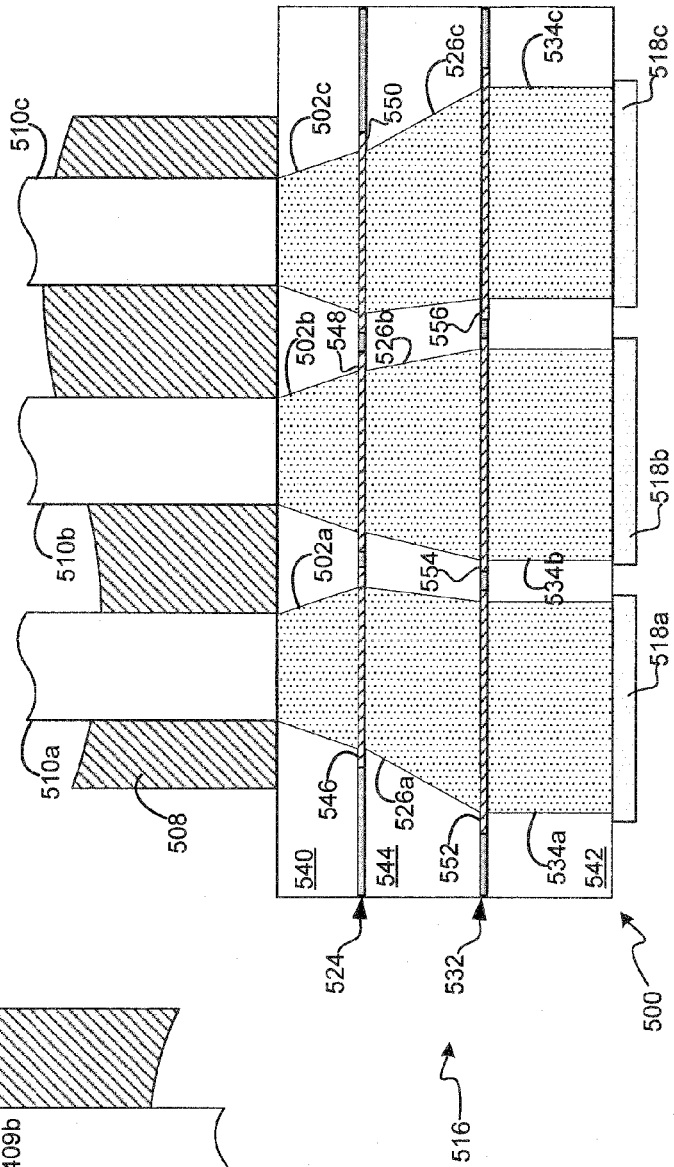


FIG. 4

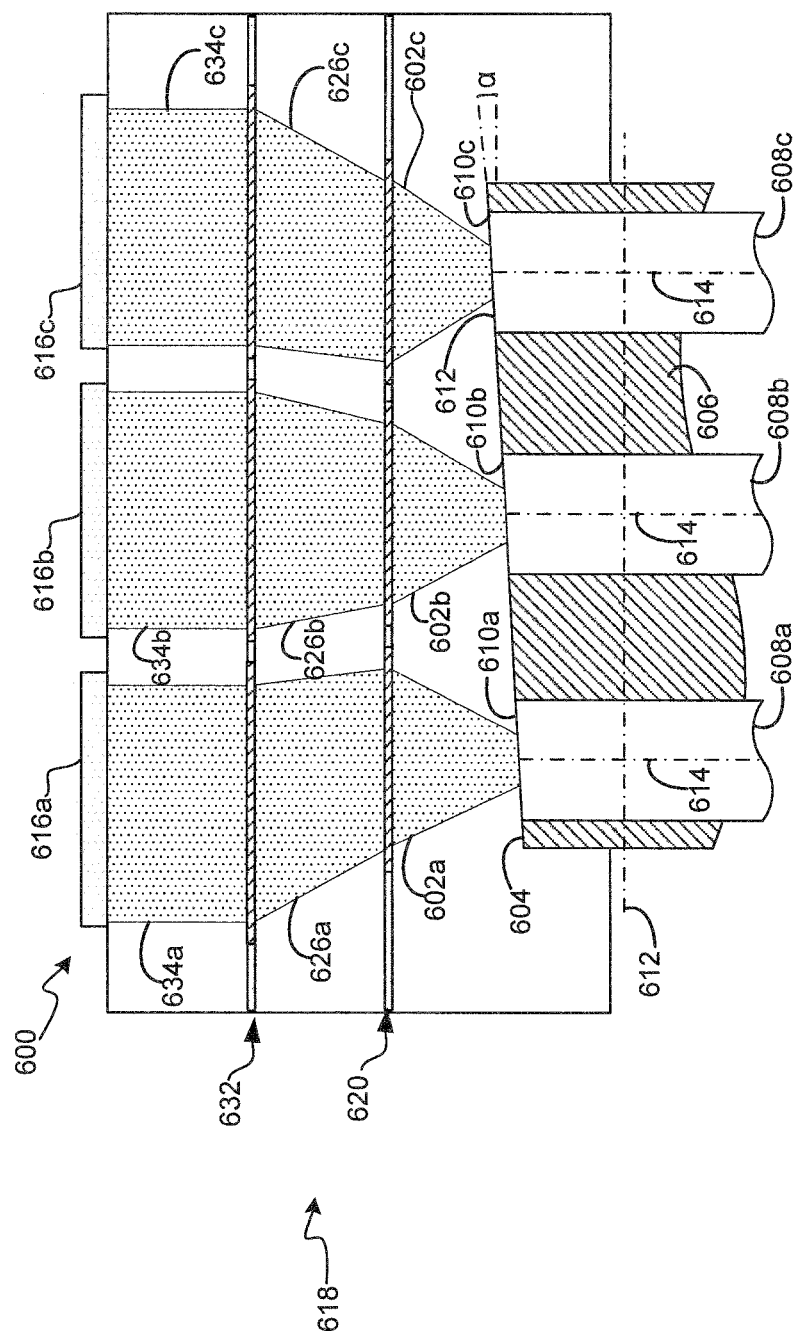


FIG. 6

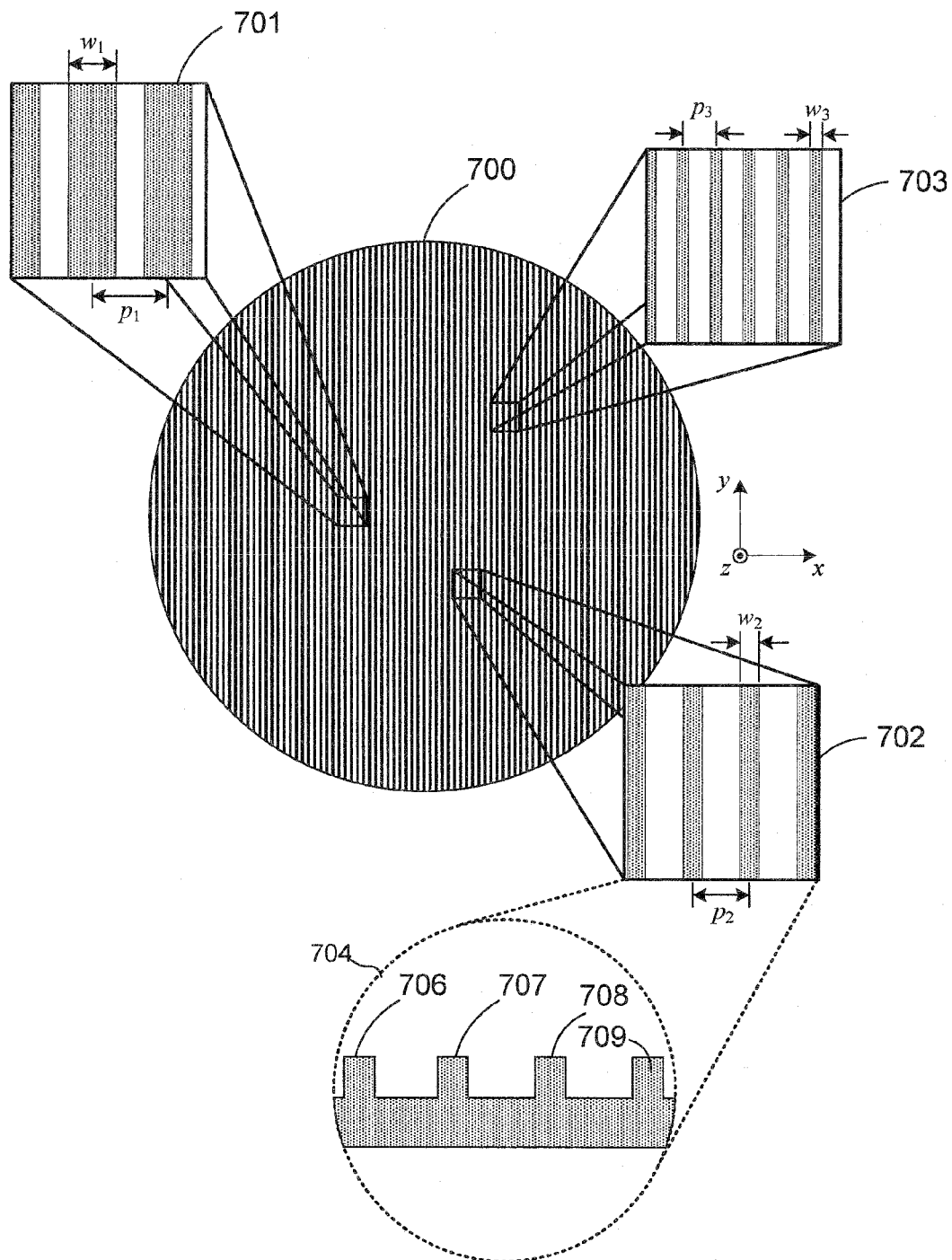


FIG. 7

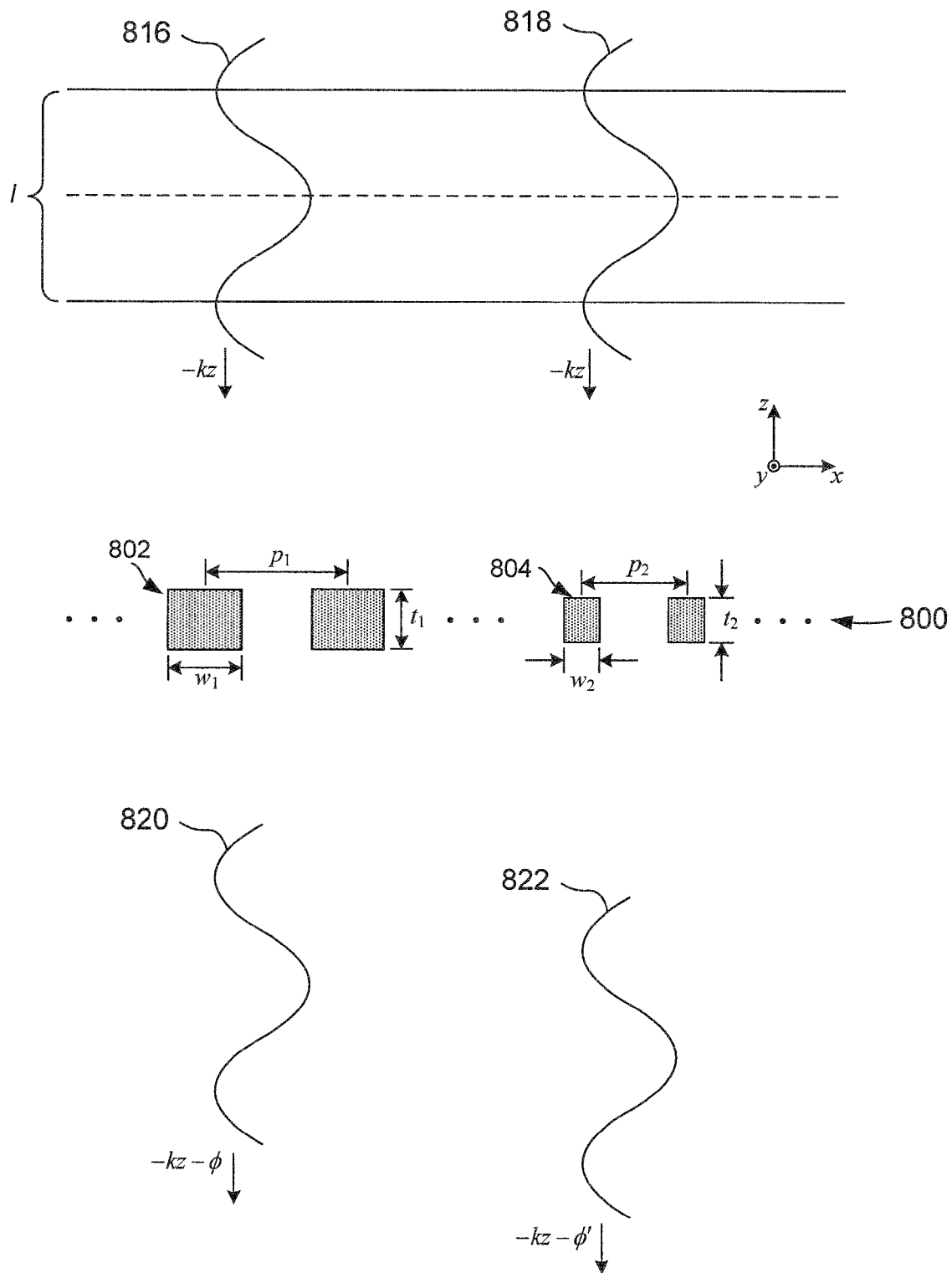


FIG. 8

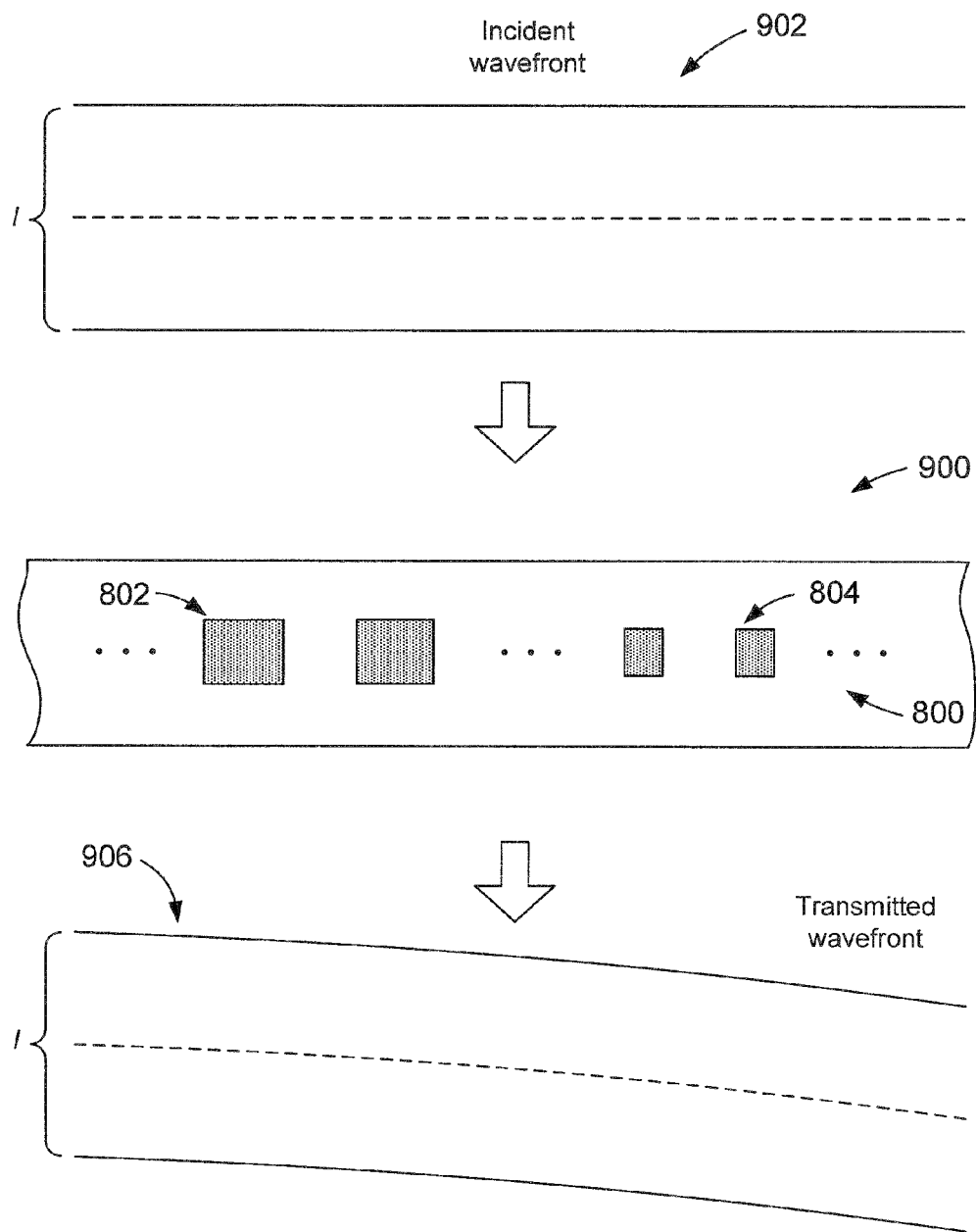


FIG. 9

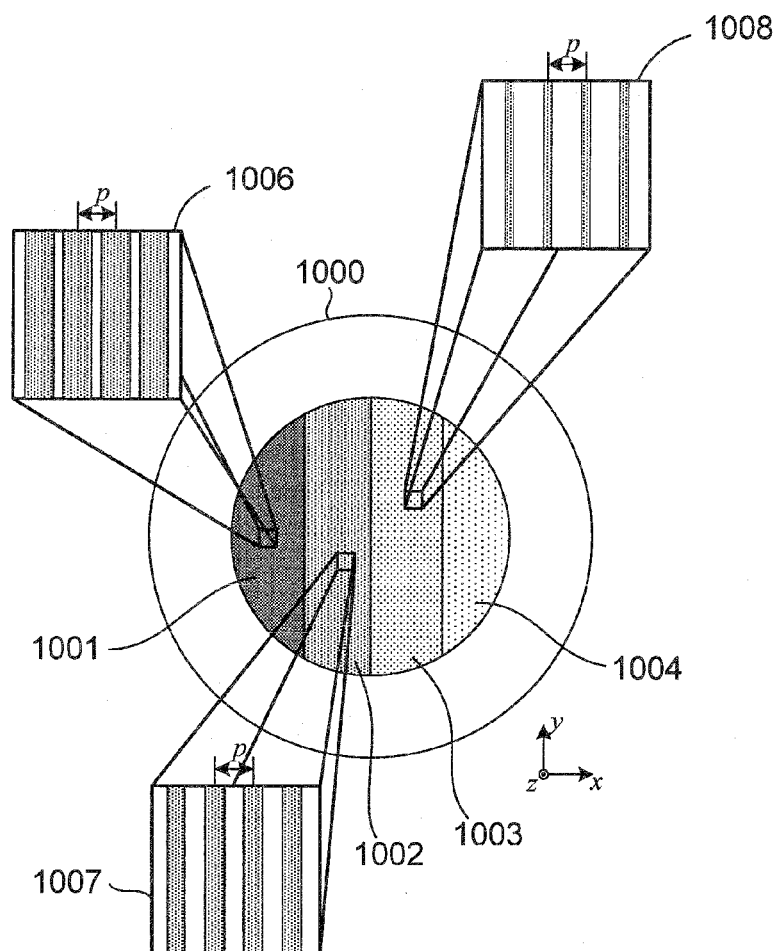


FIG. 10A

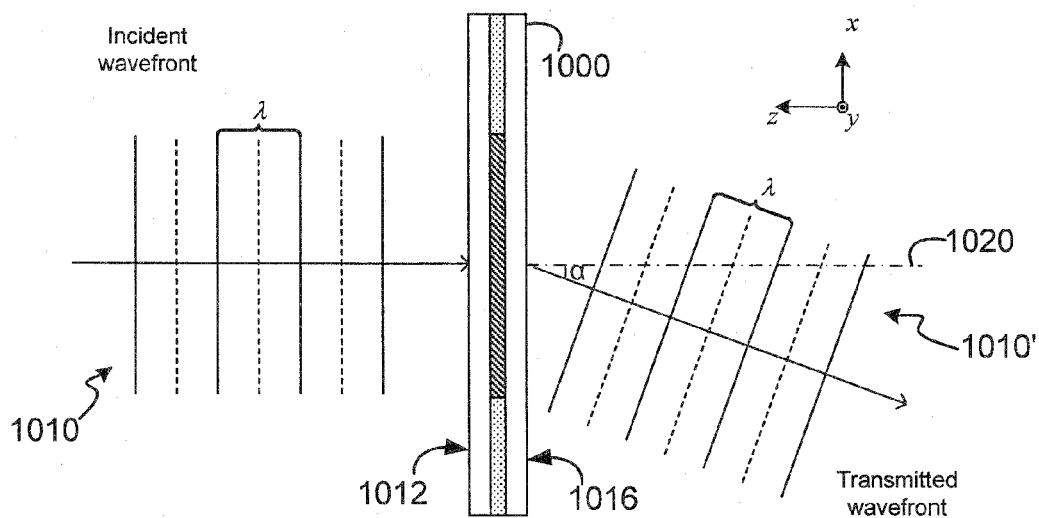


FIG. 10B

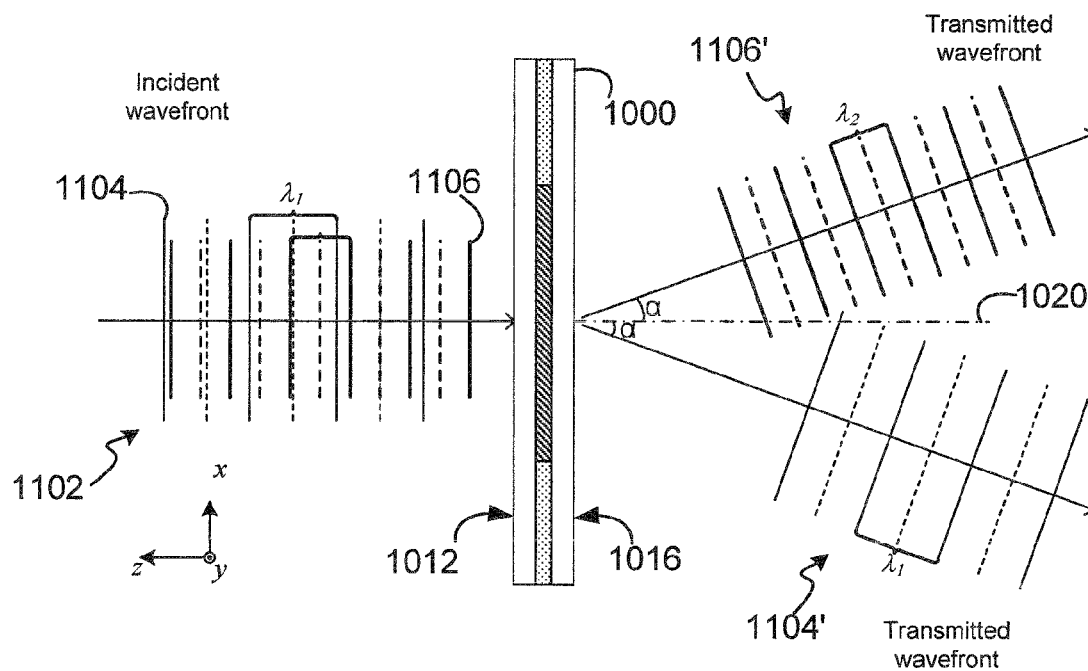


FIG. 11

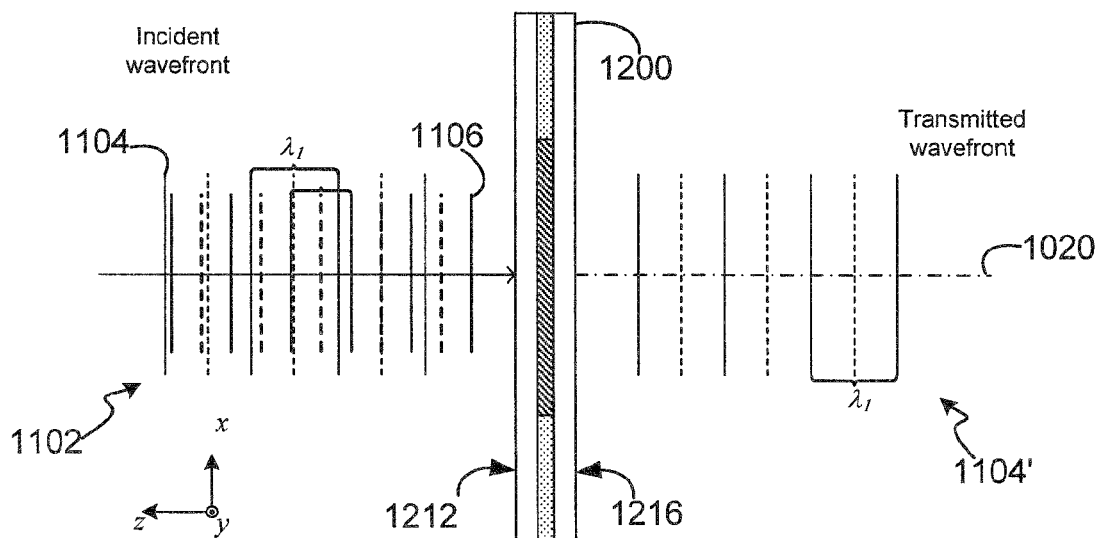


FIG. 12

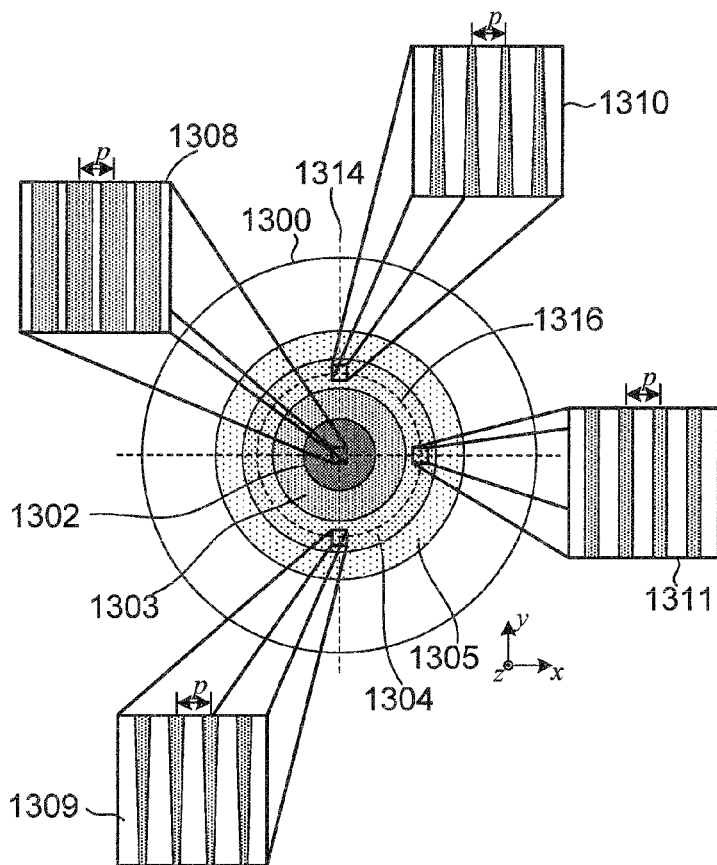


FIG. 13A

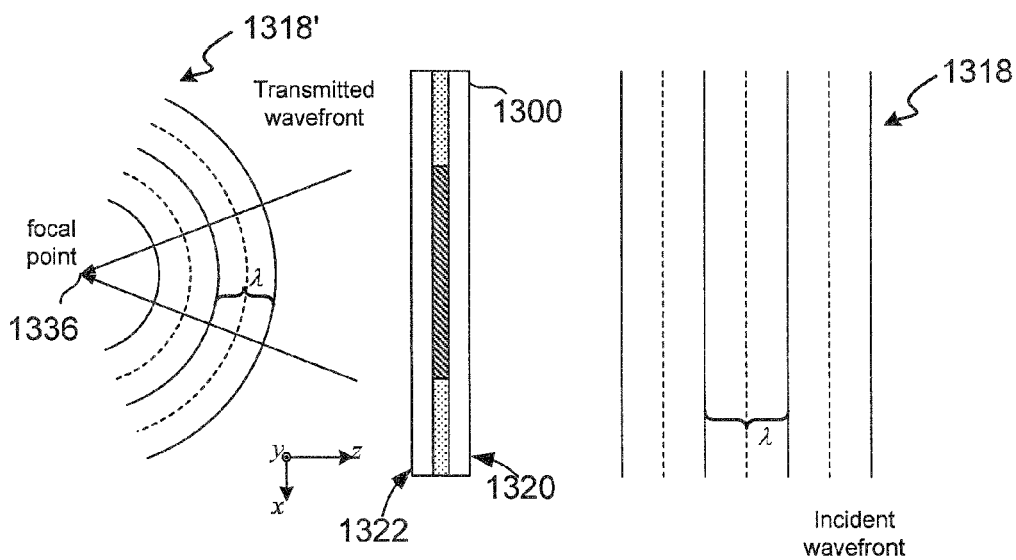
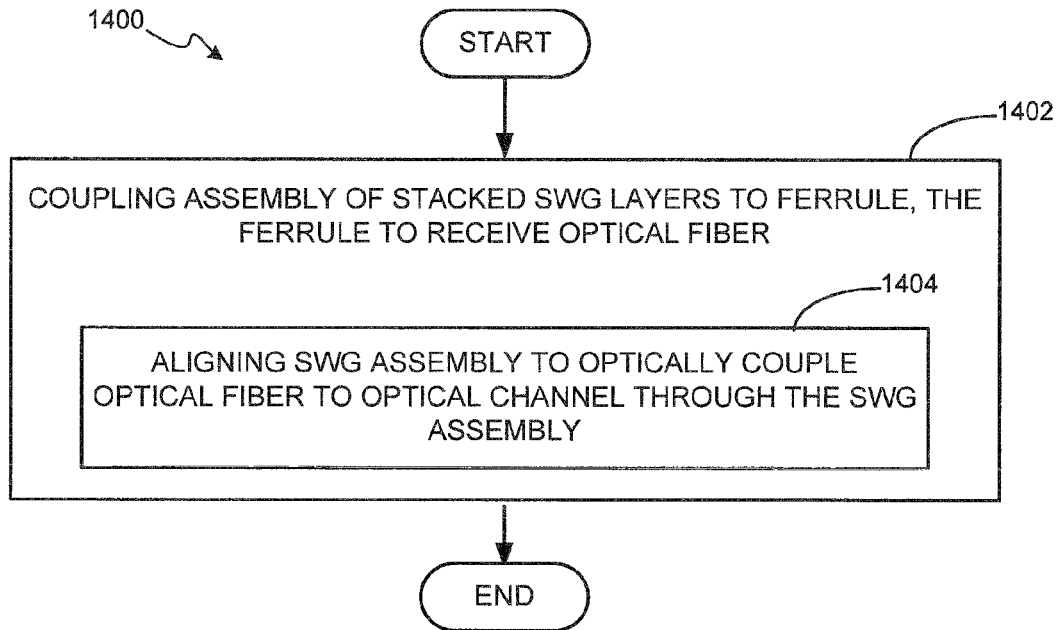
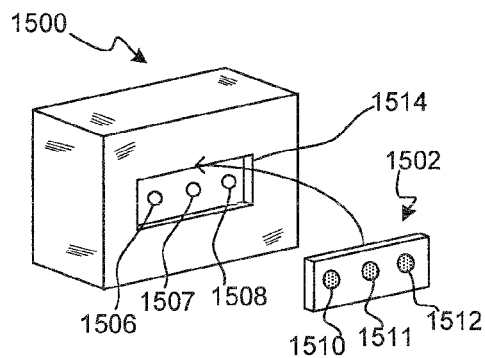
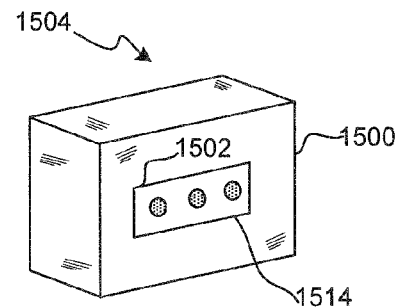


FIG. 13B

**FIG. 14****FIG. 15A****FIG. 15B**

OPTICAL CONNECTIONS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a U.S. National Stage Application of and claims priority to International Patent Application No. PCT/US2011/064128, filed on Dec. 9, 2011, and entitled "OPTICAL CONNECTIONS".

BACKGROUND

Multiple applications rely on optical interconnections. For example, transmission of high-resolution videos over the internet demands a high network bandwidth. Optical fibers may be used for transmitting data over vast distances providing high network bandwidth. Further, supplying data with an optical fiber facilitates maintaining high bandwidth all the way to the end-user without compromising power consumption. In order to serve a high number of users, data may be transmitted using a multiple terminal (MT) optical communication system. One approach to implement a MT optical communication system is to use bundles of optical fibers. Each optical fiber may carry signals for transmitting data to multiple users (e.g., 64 end-users). Another approach is to use multicore optical fiber, in which an optical fiber includes a plurality of cores, each core carrying signals for transmitting data to multiple users. For example, a multicore design may include seven cores; one core may carry a signal to 64 end-users so that the multicore can carry signals for 448 end-users.

Optical fiber connectors may be used where a connect/disconnect capability is required in an optical communication system. Optical connectors may be used to, for example, connect equipment, interconnect optical fibers, or cross-connect optical cables within a system. In an optical connector, mating ferrules may receive fibers in fixed positions such that two optical fibers mate in coaxial alignment to effect an interconnection. Such connectors may require point-to-point contact of optical fibers or implementing optical alignment using additional optical components (e.g., lenses). Optical connectors may be designed for MT optical communication systems. For example, MT optical connectors may be designed to interconnect multicore optical fibers, bundles of optical fibers, or MT optical equipment.

Optical connectors may be susceptible to environmental conditions or mechanical instabilities. Further, at least some types of optical connectors may be relatively expensive to manufacture in particular if they include additional optical elements such as lenses. Moreover, in order to assure high interconnection precision, a connector may require a number of high-precision components to be assembled together. Optical connectors may be susceptible to contamination, in particular when implementing optical alignment using lenses. MT optical connectors are generally more prone to these issues than single terminal connectors.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the present disclosure may be well understood, various examples will now be described with reference to the following drawings.

FIG. 1 is a schematic cross-sectional view of an optical device according to an example herein.

FIG. 2 is a schematic cross-sectional view of a MT optical device according to an example herein.

FIG. 3A is a schematic cross-sectional view of a disconnected multicore optical connector according to an example;

FIG. 3B is a schematic cross-sectional view of the multicore optical connector of FIG. 3A in a connected state.

FIG. 4 is a schematic cross-sectional view of a portion of an optical connector in operation to control light beams according to an example.

FIG. 5 is a schematic cross-sectional view of a portion of an optical connector in operation to control light beams according to another example.

FIG. 6 is a schematic cross-sectional view of a portion of an optical connector in operation to control light beams according to yet another example.

FIG. 7 shows a top plane view of a sub-wavelength (SWG) layer configured with a grating pattern according to an example.

FIG. 8 shows a cross-sectional view of a SWG according to an example.

FIG. 9 shows a cross sectional view of a SWG layer in operation illustrating how a transmitted wavefront may be changed according to an example.

FIG. 10A shows a top plan view of a SWG layer configured according to an example; FIG. 10B shows a cross-sectional view of the SWG layer of FIG. 10A in operation.

FIG. 11 shows a cross-sectional view of the SWG layer of FIG. 10A in operation for splitting a multiple component wavefront.

FIG. 12 shows a cross-sectional view of another example of a SWG layer in operation for filtering a spectral component of a multiple component wavefront.

FIG. 13A shows a top plan view of a SWG layer configured according to another example; FIG. 13B shows a cross-sectional view of the SWG layer of FIG. 13A in operation.

FIG. 14 shows a diagram depicting a process flow for manufacturing an optical fiber connector according to an example.

FIG. 15A is a schematic isometric view of a ferrule for a MT connection and a SWG assembly decoupled from the ferrule according to an example. FIG. 15B is a schematic isometric view of a MT optical connector including the ferrule with the SWG assembly coupled thereto according to an example.

In the drawings, the dimensions of layers and regions are exaggerated for clarity of illustration.

DETAILED DESCRIPTION

In the following description, numerous details are set forth to provide an understanding of the examples disclosed herein. However, it will be understood that the examples may be practiced without these details. Further, in the following detailed description, reference is made to the accompanying figures, in which various examples are shown by way of illustration. In this regard, directional terminology, such as "top," "bottom," "front," "back," "left," "right," "vertical," etc., is used with reference to the orientation of the figures being described. Because disclosed components can be positioned in a number of different orientations, the directional terminology is used for purposes of illustration and is in no way limiting. Like numerals are used for like and corresponding parts of the various figures. While a limited number of examples are illustrated, it will be understood that there are numerous modifications and variations therefrom.

In the following description, the term "light" refers to electromagnetic radiation with wavelength(s) in the visible and non-visible portions of the electromagnetic spectrum, including infrared and ultra-violet portions of the electromagnetic spectrum. The term "light beam" refers to a ray of light including one or more spectral components. The term "wave-

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front” refers to the locus (i.e., a line or, in a wave propagating in three dimensions, a surface) of points in a light beam having the same phase. The term “stack” refers to an ordered heap of SWG layers. Spacers may be interposed between the SWG layers of a stack. It will be understood that when a layer or film is referred to or shown as being ‘between’ two layers or films, it can be the only layer or film between the two layers or films, or one or more intervening layers or films may also be present.

As set forth above, optical devices may implement optical components for facilitating inter-connectivity. For example, a lens arrangement in a beam expansion connector may improve connector resilience. However, such optical components may result in a bulky design of the connector. Further, such optical components may significantly increase manufacturing costs. Last but not least, such optical components may be prone to suffer contamination. For example, void spaces between lenses tend to become contaminated.

Optical devices are described herein that include sub-wavelength grating (SWG) layers arranged to conveniently facilitate inter-connectivity between optical channels. More specifically, as illustrated by FIG. 1, an optical device **100** may include the following elements: (i) an input optical channel **102**; (ii) an assembly **104** of stacked SWG grating layers **108**, **110**; and (iii) an output optical channel **106**.

In the illustrated example, input optical channel **102** and output optical channel **106** have different dimensions, namely they have different diameters. SWG assembly **104** is arranged to conveniently adjust the beam diameter coupled to output optical channel **106**.

Input optical channel **102** and output optical channel **106** may correspond to, for example, optical fiber ends, inputs or outputs of photonic integrated circuits or optical transceivers, or ends of cores of a multicore optical fiber. As illustrated in FIGS. **3** to **6**, an optical device as described herein may be a connector for optical fiber. Optical devices as described herein are not limited to optical fiber connectors. Any optical devices implementing interconnectivity between optical channels are contemplated such as interconnecting portions of photonic integrated circuits (PIC), light transducers, or connectors for other types of waveguides. In some examples, a multiple terminal (MT) optical connector is illustrated that interconnects optical channels corresponding to a plurality of terminals.

Continuing to refer to FIG. **1**, SWG assembly **104** includes a first SWG layer **108**, a second SWG layer **110**, and a spacer **112** interposed therebetween. SWG layers **108**, **110** are disposed parallel to each other. Further, spacer **112** defines the relative arrangement between the SWG layers, which are aligned to optically couple input optical channel **102** and output optical channel **106**. The SWG layers can be composed of any suitable material, such as semiconductor including silicon (“Si”), gallium arsenide (“GaAs”), indium phosphide (“InP”), silicon carbide (“SiC”), or a combination thereof. In examples herein, a spacer is comprised of a solid material for separating adjacent SWG layers. The spacers may be composed of a suitable polymer or another dielectric material such as a transparent silicon oxide. A spacer may have a refractive index lower than for an adjacent SWG layers. As detailed below, a spacer may include a substrate on which one or more SWG layers are formed.

A SWG layer refers to a layer that includes a diffraction grating with a pitch that is sufficiently small to suppress all but the 0^{th} order diffraction. In contrast thereto, conventional wavelength diffraction gratings are characterized by a pitch that is sufficiently high to induce higher order diffraction of incident light. In other words, conventional wavelength dif-

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fraction gratings split and diffract light into several beams travelling in different directions. A pitch of a SWG layer may range from 10 nm to 300 nm or from 20 nm to 1 μ m. How the SWG layer refracts an incident beam may be determined at manufacturing by properly selecting the dimensions of the diffractive structure of the SWG.

As detailed below in Section CONFIGURING SUB-WAVELENGTH GRATINGS, a SWG layer may be arranged to control and/or shape an incident beam. More specifically, SWGs with a non-periodic, sub-wavelength pattern may be configured to impart an arbitrary phase front on the impinging beam. Thereby, a SWG layer may be used to implement a vast variety of optical functionalities similarly as other, more conventional, optical components (e.g., lenses, prisms, mirrors, polarizers, beam splitters, or optical filters).

Referring back to FIG. **1**, device **100** may operate as follows. Input optical channel **102** may emit a diverging light beam **114**. Beam **114** may originate from an optical fiber (not shown) coupled to input optical channel **102**. Diverging beam **114** propagates through medium **116**. Medium **116** may be comprised of a solid layer (e.g., a transparent oxide layer) integrated in SWG assembly **104**. Medium **116** comprised of a solid layer prevents that contamination enters into the optical path of device **100**. In some examples, medium **116** is air or any other material that suitably transmits light.

Diverging beam **114** impinges on first SWG layer **108**. First SWG layer **108** is arranged to collimate diverging beam **114** into a collimated beam **118**. Collimated beam **118** propagates through spacer **112** and impinges on second SWG layer **110**. Second SWG layer **110** is arranged to converge collimated beam **118** towards output optical channel **106**. Converging beam **120** propagates through medium **122**, which may be constituted similarly to medium **116**, and impinges on output optical channel **106**. As illustrated, the diameter of converging beam **120** at output channel **106** corresponds to the channel diameter.

SWGs layers **108**, **110** are implemented as stacked layers. Thereby, a compact implementation of specific optical functionalities in device **100** is facilitated. Moreover, optical devices described herein implement these particular optical functionalities using a SWG assembly that can be mass-produced. Moreover, SWG assembly **104** does not compromise an accurate optical alignment since SWG layers may be easily fabricated using micro-fabrication procedures and high volume production methods such as standard CMOS processes or roll-to-roll imprinting.

Some examples implement a MT optical device. By way of example, a MT optical device may be designed for any of the following applications: interconnecting multicore optical fibers; interconnecting bundles of optical fibers; connecting MT optical fiber arrangements (e.g., implementing multicore fibers or optical fiber bundles) to a PIC or an optical transceiver; splicing MT optical fiber arrangements; or interconnecting PICs or optical transceivers with multiple terminals.

A MT optical device includes a plurality of input optical channels and a plurality of corresponding output optical channels. One input optical channel and its corresponding output optical channel implement one terminal FIG. **2** is a schematic cross-sectional view of a MT optical device **200** according to an example herein. MT optical device **200** includes input optical channels **202-204**, a SWG assembly **208**, and output optical channels **210-212**. Input optical channels **202-204** and output optical channels **210-212** may correspond to, for example, optical fiber ends of a bundle of optical fibers, ends of cores of a multicore optical fiber, inputs or outputs of photonic integrated circuits. In the illustrated example, input optical channels **202-204** have a different

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dimension than output optical channels **210-212**, namely they have different diameters. SWG assembly **208** is arranged to conveniently adjust the beam diameter coupled to output optical channel **210-212**.

According to some examples, a MT optical device may include a SWG assembly as described above. SWG assembly **208** includes a first array **216** of SWG layers **218-220** and a second array **224** of SWG layers **226-228**. Arrays **216** and **224** are stacked with a spacer **232** disposed therebetween. In the illustrated example, the SWG layers in one of the SWG layers are formed separated from each other. In alternative examples, the SWG layers in one of the SWG arrays are continuously formed as a single layer contiguous to spacer **232**.

According to examples herein, a SWG assembly in a MT device is aligned to optically couple input optical channels to output optical channels so as to implement optical connectivity for each terminal. As illustrated in FIG. 2, SWG layers may be disposed opposite to each other so as to interconnect corresponding channels in one terminal similarly as described above with respect to FIG. 1. For example, SWG layer **218** is disposed opposite to SWG layer **226** with a portion of spacer **232** build in-between. Further, SWG assembly **208** is aligned to optically couple input optical channels **202-204** to output optical channels **210-212**. More specifically, each of the SWG layers in first array **216** corresponds to one of the input optical channels and is aligned therewith (e.g., SWG layer **218** is aligned with input optical channel **202**); each of the SWG layers in second array **224** corresponds to one of the output optical channels and is aligned therewith (e.g., SWG layer **226** is aligned with output optical channel **210**).

In the particular example shown in FIG. 2, SWG array **216** corresponds to a SWG sub-assembly arranged to collimate diverging beams **234-236** emitted from input optical channels **202-204** into beams **240-242**; SWG array **216** corresponds to a SWG sub-assembly arranged to converge collimated beams **240-242** into converging beams **244-246** directed towards output optical channels **210-212**.

Using stacked SWG layers as interconnecting optical elements facilitates a compact design of MT devices. Moreover, such stacked SWG layers can be fabricated in a simple manner without compromising optical alignment in one terminal. Further, spacers in the SWG arrangement prevent contamination within a MT device, since void spaces are reduced between the optical elements. For example, a solid layer **250** may be provided in-between input optical channels **202-204** and SWG layers **218-220**; a solid layer **252** may be provided in-between SWG layers **226-228** and output optical channels **210-212**. Solid layers **250**, **252** and SWG assembly **208** may be manufactured as a single integrated structure using micro-fabrication techniques.

As set forth above, a MT optical device as described herein may be configured to interconnect a multicore optical fiber with other optical devices (e.g., another optical fiber, a PIC or an optical transceiver, or single optical fibers in a splicer).

FIG. 3A is a schematic cross-sectional view of a disconnected multicore optical connector **300** according to an example; FIG. 3B is a schematic cross-sectional view of multicore optical connector **300** in a connected state. In this example, connector **300** includes a first connector element **302** and a second connector element **304**. First connector element **302** includes a ferrule **306** with an opening **308** for receiving a multicore optical fiber **310**. Multicore optical fiber **310** includes cores **312-315**. Opening **308** is arranged such that cores **312-315** may abut a first end face **320** of a SWG assembly **322** when multicore optical fiber **310** is mounted

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into ferrule **306**. Second connector element **304** includes a ferrule **324** with an opening **326** for receiving a multicore optical fiber **328**. Multicore optical fiber **328** includes cores **330-333**. Opening **326** is arranged such that cores **330-333** may abut a second end face **336** of SWG assembly **322** when connector **300** is in a connected state (see FIG. 3B).

First connector element **302** and second connector element **304** may include mating elements for coupling these elements to each other when connector **300** is in a connected state. Such mating elements may collaborate to optically align optical fiber **308**, SWG arrangement **322**, and optical fiber **328**. The mating elements may be implemented as a pin-and-hole assembly. In the illustrated example, holes **340**, **342** are formed in ferrule **306** of first connector element **302**, and pins **344**, **346** (complementary to holes **340**, **342**) are formed in ferrule **324** of second connector element **304**. It will be understood that other suitable mating arrangements may be provided for coupling the connector elements. For example, mating connector parts may be fixed to the ferrules through a holder and used to couple connector elements **302**, **304**.

FIGS. 3A and 3B above illustrate a MT optical connector for interconnecting multicore optical fibers. More specifically, SWG assembly **322** is arranged at ferrule **306** to optically couple corresponding cores of fibers **310**, **328** (e.g., SWG assembly **322** is aligned to couple core **312** of multicore optical fiber **310** to core **330** of multicore optical fiber **328**).

In some applications, it is convenient to control the beams coupled into an MT connector. In particular, the spacing and/or arrangement between optical channels to be interconnected may differ in spacing and/or arrangement. A MT optical connector including a SWG assembly to control beams emitted from a plurality of channels is contemplated herein, as illustrated in FIGS. 4 to 6. Such MT optical connectors are exemplified below with respect to multicore optical fiber. It will be understood that such MT optical connectors may be used to interconnect any MT optical device.

In the examples illustrated in FIGS. 4 to 6, SWG assemblies are specifically configured to separate and collimate a plurality of beams. Such a SWG assembly may be particularly convenient for optically coupling input channels with output channels having different relative spatial separations. Such situation may, for example, arise when interconnecting a multicore optical fiber with an optical device such as a PIC or an optical transceiver.

FIG. 4 is a schematic cross-sectional view of a portion of an optical connector **400** according to an example. Optical connector **400** is shown in operation to control light beams **402a**, **402b** emitted from a multicore optical fiber **406**. In this example, a two-core optical fiber is illustrated including cores **408a**, **408b** that are optically coupled to optical channels **430a**, **430b** through a SWG assembly **401**. It will be understood that optical connector **400** may be adapted to control beams emitted from a multicore optical fiber with any number and arrangement of cores. Optical fiber **406** may be supported by a ferrule (not shown) to which SWG assembly **401** is mechanically coupled so as to be optically aligned with ends **409a**, **409b** of cores **408a**, **408b**.

SWG assembly **401** includes the following SWG sub-assemblies: (i) a SWG collimating sub-assembly **412** to individually collimate beams **402a**, **402b** emitted from cores **408a**, **408b** into collimated beams **414a**, **414b**; (ii) a first SWG deflection sub-assembly **418** to individually deflect beams **414a**, **414b** collimated at the SWG collimating sub-assembly **412** so as to separate collimated beams **414a**, **414b** into deflected beams **420a**, **420b**; and (iii) a second SWG deflection sub-assembly **424** to further deflect beams **420a**, **420b** deflected at first SWG deflection sub-assembly **418** into

parallel beams **426a**, **426b** directed towards optical channels **430a**, **430b**. Optically channels **430a**, **430b** may correspond to, or be optically connected to, inputs of an optical device (not shown) to which optical fiber **406** is interconnected through connector **400**.

As illustrated in FIG. 4, each SWG sub-assembly may include one or more SWG layers for controlling or shaping individual beams. For example, SWG collimating sub-assembly **412** includes a SWG layer **434** arranged to collimate incident beams **402a**, **402b**; first SWG deflection sub-assembly **418** includes a SWG layer **436** arranged to deflect incident beams **412a**, **414a**; second SWG deflection sub-assembly **424** includes two horizontally aligned SWG layers **438**, **440** each of them configured to deflect, respectively, incident beams **420a**, **420b**.

SWG assembly **401** includes spacers **442**, **444** interposed between the SWG sub-assemblies. Further, a medium **446** may be interposed between SWG collimating sub-assembly **412** and ends **409a**, **409b** of cores **408a**, **408b**; a medium **448** may be interposed between second SWG deflection sub-assembly **424** and optical channels **430a**, **430b**. Media **446**, **448** may be provided as a solid layer similar to spacers **442**, **444** so as to reduce free spaces in connector **400**. As set forth above, such free spaces may be prone to contamination that may reduce optical performance of the connector. Alternatively, media **446**, **448** may be air or any other suitable fluid. The refractive index of media interposed between channels of an optical connector (e.g., media **446**, **448**) may be matched to the refractive index of adjacent optical elements, such as adjacent cores or optical channels, in order to pre-set how beams propagate in the media.

As illustrated by FIG. 4, connector **400** may operate as follows. Cores **408a**, **408b** may emit diverging beams **402a**, **402b**. Diverging beams **402a**, **402b** propagate through medium **446** and impinge on SWG collimating sub-assembly **412**. SWG collimating sub-assembly **412** collimates diverging beams **402a**, **402b** into collimated beams **414a**, **414b**. Collimated beams **414a**, **414b** propagate through spacer **442** and impinge on first SWG deflection sub-assembly **418**. First SWG deflection sub-assembly **418** deflects and, thereby, separates collimated beams **414a**, **414b** into deflected beams **420a**, **420b**. Deflected beams **420a**, **420b** propagate through spacer **444** and impinge on second SWG deflection sub-assembly **424**. Second SWG deflection sub-assembly **424** deflects beams **420a**, **420b**, thereby, generating parallel beams **426a**, **426b** directed towards optical channels **430a**, **430b**.

In some examples, as illustrated by FIGS. 5 and 6, a SWG assembly may function not only for separating beams but also to expand the beams so as to increase resilience of the optical connection. As set forth above, optical connectors may be susceptible to environmental conditions or mechanical instabilities. For example, changing environment conditions, or mechanical instabilities, may affect alignment of optical channels in the connector. Such issues may be addressed using beam expansion. Beam expansion provides resilience in the optical connection so that interruption of the optical connection by relative displacements of connector component is prevented. Therefore, by expanding the beam within the connector, the optical inter-connection is less susceptible to changing environmental conditions or mechanical instabilities.

Conventionally, beam expansion connectors may include a lens arrangement that expands a beam and couples the expanded beam into an output optical channel. However, such a lens arrangement may be particularly prone to contamination in free spaces formed between lenses. Contamination

may disperse and/or attenuate optical signals, thereby worsening optical performance of the connector. Moreover, a lens arrangement may result in a bulky design of the connector. Last but not least, implementing a lens arrangement may significantly increase manufacturing costs. An SWG assembly as illustrated facilitates addressing such issues.

FIG. 5 is a schematic cross-sectional view of a portion of an optical connector **500** according to an example. Optical connector **500** is shown in operation to control beams **502a-502c** emitted from a multicore optical fiber **508**. In this example, a three-core optical fiber is illustrated including lateral cores **510a**, **510c** and middle core **510b**. A SWG assembly **516** optically couples cores **510a-510c** to optical channels **518a-518c**.

SWG assembly **516** includes the following SWG sub-assemblies: (i) a SWG expanding sub-assembly **524** to individually expand beams **502a-502c**, propagating through medium **540**, into beams **526a-526c**, and (ii) a SWG collimating sub-assembly **532** to individually collimate beams **526a-526c** into collimated beams **534a-534c**. SWG assembly **516** further includes spacers **544** interposed between SWG sub-assemblies **524**, **532**. Media **540**, **542** may be provided as solid transparent layers integrated in SWG assembly **516**.

As illustrated in FIG. 5, SWG expanding sub-assembly **524**, in addition to beam expansion, also deflects beams **502a**, **502c** emitted from lateral cores **510a**, **510c** so as to separate lateral beams **502a**, **502c** from middle beam **502b**. Thereby, interference between the expanded beams is prevented. Further, SWG collimating sub-assembly **532** is additionally arranged to deflect beams **526a**, **526c** such that collimated beams **534a-534c** propagate parallelly to each other through medium **542**.

Each of SWG sub-assemblies **524**, **532** include SWG layers arranged to implement the above optical functions. More specifically, expanding SWG sub-assembly **524** includes SWG layers **546**, **548**, **550**: SWG layers **546**, **550** are arranged to expand and deflect, respectively, lateral beams **502a**, **502c**; SWG layer **548** is arranged to expand middle beam **502b**. Further, SWG collimating sub-assembly **532** includes SWG layers **552**, **554**, **556**: SWG layers **552**, **556** are arranged to collimate and deflect, respectively, lateral beams **526a**, **526c**; SWG layer **554** is arranged to collimate middle beam **526b**. The SWG layers in a sub-assembly are shown to be formed separate from each other. Alternatively, the SWG layers in a sub-assembly may be integrated in a single SWG layers with regions implementing the optical function of each individual SWG layer.

According to some examples, as illustrated in FIG. 6, the connector may be adapted to optically couple light emitted from a multicore optical fiber end with an angled facet. An angled facet refers to an end of an optical fiber cut such that its surface forms an oblique angle with respect to a longitudinal axis (e.g., axis **614** in FIG. 6) of the core ends. Angled facets prevent modal back-reflection at the core end. A SWG assembly as described herein facilitates an easy interconnection of such optical fibers with other optical devices without compromising coupling efficiency.

FIG. 6 is a schematic cross-sectional view of a portion of an optical connector **600** according to an example. Optical connector **600** is for a multicore optical fiber **606** including three cores **608a-608c** with core ends **610a-610c**. Optical connector **600** is illustrated in operation to control beams **602a-602c** emitted from core ends **610a-610c** abutting an angled facet **604** of multicore optical fiber **606**. Angled facet **604** forms an angle α with respect to an emission plane **612** defined by the longitudinal axis **614** of core ends **610a-610c**.

Connector **600** includes a SWG assembly **618** arranged to optically couple cores **608a-608c** to optical channels **616a-616c**. SWG assembly **616** is arranged similarly to SWG assembly **516**: (i) a SWG expanding sub-assembly **620** is arranged to individually expand beams **602a-602c**, propagating through medium **540**, into beams **626a-626c**, (ii) SWG expanding sub-assembly **620** is also arranged to separate lateral beams **602a**, **602c** from middle beam **602b**, (iii) a SWG collimating sub-assembly **632** is arranged to individually collimate beams **626a-626c** into collimated beams **634a-634c** directed towards optical channels **616a-616c**, and (iv) SWG collimating sub-assembly **632** is also arranged to deflect lateral expanded beams **626a**, **626c** such that collimated beams **643a-643c** propagate parallelly.

The connector illustrated above with regard to FIGS. **5** and **6** are examples of expanded beam connector. In contrast to point-to-point contact connectors, which may require an exact alignment of the channels susceptible to environmental changes or mechanical instabilities, such an expanded beam connector are resilient to relative lateral displacements between the optical channels or other components of connector. Further, these connectors implement beam separation in combination with beam expansion, thereby preventing interference between the beams. Since the above connectors are based on stacked SWG layers, they may be compactly built although they implement relatively complex optical functions. Although the above examples illustrate beam expansion for MT connectors, it will be understood that beam expansion may be analogously implemented for connectors implementing a single terminal (For example, such a single-terminal connector may implement the optical functionalities of SWG assembly **516** with SWG layers **548**, **554** for expanding a beam without deflection thereof similarly as illustrated for beam **502b**.)

Configuring Sub-Wavelength Gratings: FIG. **7** shows a top plane view of a SWG layer **700** configured with a grating pattern according to an example. In this example, SWG layer **700** includes a number of one-dimensional grating sub-patterns. Three grating sub-patterns **701-703** are depicted enlarged. Each grating sub-pattern includes a number of regularly arranged diffractive structures. In the depicted example, the diffractive structures are illustrated as spaced wire-like portions of SWG layer material (hereinafter referred to as "lines"). The lines extend in the y-direction and are spaced in the x-direction. An enlarged end-on view **704** of grating sub-pattern **702** is also depicted. As illustrated by end-on view **704**, SWG layer **700** may be a single layer with lines, such as lines **706-709**, separated by grooves formed in the layer.

A sub-pattern of a SWG layer is characterized by one or more periodic dimensions characteristic of the diffractive structure. In the illustrated example, the periodic dimensions correspond to (a) the spacing of the lines, and (b) the line width in the x-direction. More specifically, sub-pattern **701** comprises lines of width w_1 periodically spaced with a period p_1 ; sub-pattern **702** comprises lines with width w_2 periodically spaced with a period p_2 , and the sub-pattern **703** comprises lines with width w_3 periodically spaced with a period p_3 . A grating sub-patterns form a sub-wavelength grating if a characteristic dimension thereof (e.g., periods p_1 , p_2 , or p_3) is smaller than the wavelength of the particular incident light for which it is designed to operate. For example, a characteristic dimension of a SWG (e.g., periods p_1 , p_2 , or p_3) can range from 10 nm to 300 nm or from 20 nm to 1 μ m. Generally, the characteristic dimensions of a SWG are chosen depending on the wavelength of the light for which a particular optical device is designed to operate.

0^{th} order diffracted light from a sub-region acquires a phase ϕ determined by the line thickness t , and the duty cycle η , which may be defined by:

$$\eta = \frac{w}{p},$$

where w is the line width and p is the period of the lines associated with the region.

Each of the grating sub-patterns **701-703** diffract incident light differently due to the different duty cycles and periods associated with each of the sub-patterns. SWG layer **700** may be configured to interface incident light in a specific manner by adjusting the period, line width, and line thickness of the lines.

FIG. **8** shows a cross-sectional view of a SWG **800** according to an example. The Figure depicts portions of two separate grating sub-patterns **802** and **804** of SWG **800**. The sub-patterns **802** and **804** can be located in different regions of SWG **800**. The thickness t_1 of the lines of sub-pattern **802** are greater than the thickness t_2 of the lines of sub-pattern **804**, and the duty cycle η_1 associated with the lines in sub-pattern **802** is greater than the duty cycle η_2 associated with the lines of sub-pattern **804**.

FIGS. **7** and **8** illustrate SWGs based on a grating with a non-periodic sub-wavelength pattern. Such SWGs are characterized by a spatially varying refractive index, which facilitates implementing an arbitrary diffractive element. The basic principle is that light incident on a non-periodical SWG (e.g., SWG **800**) may become trapped therein and oscillate for a period of time within portions of the grating. The light is ultimately transmitted through the SWG, but with the portion of light transmitted through a sub-region (e.g., sub-region **802**) acquiring a larger phase shift than the portion of light transmitted through a sub-region with different characteristic dimensions (e.g., sub-region **804** with respect to sub-region **802**).

As shown in the example of FIG. **8**, incident wavefront **816** and **818** impinge on SWG **800** with the same phase, but a wavefront **820** is transmitted through sub-pattern **802** with a relatively larger phase shift ϕ than the phase shift ϕ' acquired by a wavefront **822** transmitted through sub-pattern **804**.

In some examples, a SWG layer may be provided with reflecting layers disposed parallel to the SWG and adjacent to opposite sides thereof. Thereby, resonant cavities may be formed on both sides of the SWG. Light may then become trapped on these resonant cavities and become ultimately transmitted through the reflection layers with different phases in the beam similarly as shown in FIG. **8**.

A SWG layer may be arranged with so-called polarized diffractive elements (hereinafter referred to as polarized SWG layer). In a polarized SWG layer, how light is reflected or transmitted therethrough depends on the specific polarization of incident light. More specifically, elements of the SWG may be arranged to be sensitive to polarization of incident light. The thickness and pitch of the SWG may be chosen to be polarization sensitive as described in the international patent application with publication number WO 2011/136759, which is incorporated herein by reference to the extent in which this document is not inconsistent with the present disclosure and in particular those parts thereof describing SWG design.

Alternatively, a SWG layer may be arranged with so-called unpolarized diffractive elements, so that how light is reflected or transmitted does not substantially depend on the specific

polarization of incident light. More specifically, elements of the SWG may be arranged to be insensitive to polarization of incident light. Such SWG layers are referred to as unpolarized SWGs.

An unpolarized SWG is designed by an appropriate selection of the pattern dimensions. A transmission curve indicative of resonances for particular characteristics dimensions of the SWG may be used to design an unpolarized SWG. More specifically, for arranging a SWG layer with unpolarized diffractive elements, plots of transmittance and phase shift as a function of duty cycle for a particular design of a SWG layer may be obtained. Resonances for particular duty cycle values may be identified in these plots. (Resonances correspond to duty cycle values, where the reflection peaks and the transmission drops while undergoing a phase jump.) Generally, between these two resonances, the transmission is high and the transmitted phase varies smoothly. Using this data, an unpolarized transmissive SWG can be designed. More specifically, the dimensions of diffractive elements in the SWG layer may be chosen such that the transmission characteristics of sub-patterns of the grating are comprised between resonances in the transmission curves so that a SWG is insensitive to polarization of an incident wavefront.

Following the above procedures, an unpolarized SWG layer may be arranged to control a wavefront incident thereon or to perform other optical functions such as focusing, collimating, or expanding a wavefront incident thereon. The basic principle is to choose the dimensions of the dimensions of diffractive elements in the SWG such that the transmission characteristics of sub-patterns of the grating are comprised between resonances in the transmission curves. Moreover, using such design approach, a SWG layer may be arranged with a low aspect ratio such as an aspect ratio below 10:1 or, more specifically, an aspect ratio below 5:1 or, even more specifically, an aspect ratio below 1:1. Thereby, it is facilitated a straightforward mass production of SWG layers using micro-fabrication processes such as deep-UV or nano-imprint lithography.

Some examples of SWG layers with unpolarized diffractive elements are illustrated the article titled "A Silicon Lens for Integrated Free-Space Optics," by Fattal et al. published in Integrated Photonics Research, Silicon and Nanophotonics, OSA Technical Digest (CD) (Optical Society of America, 2011), which is incorporated herein by reference to the extent in which this document is not inconsistent with the present disclosure and, in particular, those parts thereof describing SWG design. It will be understood that the examples illustrated in this article may be generalized for a vast variety of SWG geometries such as the SWG geometries illustrated with respect to FIGS. 7, 10A, or 13A.

FIG. 9 shows a cross sectional view of a SWG layer 900 in operation illustrating how a transmitted wavefront may be changed according to some examples. In the example, incident light with a substantially uniform wavefront 902 impinges on SWG layer 900 producing transmitted light with a curved transmitted wavefront 906. Transmitted wavefront 906 results from portions of incident wavefront 902 interacting with sub-region 802 of SWG 800 with a relatively larger duty cycle η_1 and thickness t_1 than portions of incident wavefront 902 interacting with sub-region 804 of SWG 800 with a relatively smaller duty cycle η_2 and thickness t_2 . The shape of the transmitted wavefront 906 is consistent with the larger phase acquired by light interacting with sub-region 802 relative to the smaller phase shift acquired by light interacting with the sub-region 804.

Therefore, a SWG layer may be configured to provide arbitrary phase front shape modulation. Thereby, a SWG

layer may be implemented in an optical device as described herein to implement a vast variety of optical functions. These functions may include, but are not limited to, deflecting a beam, splitting a beam into spectral components, filtering one or more spectral components in a beam, polarizing a beam, focusing or defocusing a beam, or collimating a beam with a non-parallel wavefront. In the following, some examples of SWG layers configured to implements these functions are illustrated.

A non-periodical SWG may be configured so that the SWG layer operates like a prism, i.e. controlling incident light by producing transmitted light that is deflected relative to the incident light. Such a SWG may be realized by forming a pattern with a duty cycle progressively varying in one direction.

FIG. 10A shows a top plan view of a one-dimensional grating pattern of a SWG layer 1000 configured to be operated as a prism for normal incident light of an appropriate wavelength; FIG. 10B shows a cross-sectional view of SWG layer 1000 in operation. A non-periodic SWG of SWG layer 1000 includes regions 1001-1004, with each region formed from lines extending in the y-direction, having the same period, but with the duty cycle progressively decreasing from region 1001 to region 1004. Enlargements 1006-1008 show that line period spacing p is the same throughout, but the lines of region 1001 have a relatively larger duty cycle than the lines of region 1002, which have a larger duty cycle than the lines of region 1003. The duty cycles for regions 1001-1004 are selected such that the resulting phase change in transmitted light is largest for region 1001 and decreases from region 1001 to region 1004.

As depicted in FIG. 10B, the phase change causes a parallel wavefront 1010 (corresponding to a beam of light with wavelength λ directed normal to an input surface 1012 of SWG layer 1000) to be transmitted through an output surface 1016 of SWG layer 1000 as a transmitted wavefront 1010' traveling with an angle α away from a surface normal 1020.

In examples, a non-periodical SWG configured to operate like prism may act as a beam splitter when light including multiple spectral components impinges thereon.

FIG. 11 shows a cross-sectional view of SWG layer 1000 in operation for splitting a wavefront 1102 composed of multiple spectral components. In the illustrated example, wavefront 1102 includes (i) a first spectral component 1104 corresponding to light of wavelength λ_1 (illustrated with thin lines), and (ii) a second spectral component 1106 corresponding to light of wavelength λ_2 (illustrated with thick lines). SWG layer 1000 induces different phase changes to the different spectral component of the incident wavefront since interaction of light with the grating pattern is wavelength dependent.

The diffractive features of SWG layer 1000 may be designed to control a multiple-component wavefront as required for a particular application thereof. In the example depicted in FIG. 11, SWG layer 1000 is designed to control wavefront 1102 such that the spectral components thereof are deflected at symmetrical angles α . More specifically, the phase change induced by SWG layer 1000 causes (i) the spectral component 1104 of wavefront 1102, corresponding to a beam of light with wavelength λ_1 , to be transmitted through output surface 1016 as a transmitted wavefront 1104' propagating with an angle α away in the clockwise direction from surface normal 1020, and (ii) spectral component 1106 of wavefront 1102, corresponding to a beam of light with wavelength λ_2 , to be transmitted through output surface 1016 as a transmitted wavefront 1106' propagating with an angle α in the counter-clockwise direction away from surface normal

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1020. It will be understood that a SWG layer may be designed to split a multiple-component wavefront in any manner as required for implementing a specific function in an optical device. In examples, a non-periodical SWG of a SWG layer may be configured to control an incident wavefront by operating like a filter element when light including multiple spectral components impinges thereon.

FIG. 12 shows a cross-sectional view of SWG layer 1200 in operation for filtering a particular spectral component of a wavefront 1102 composed of spectral components 1104, 1106 described with respect to FIG. 11. SWG layer 1200 induces different phase changes to the different spectral component of the incident wavefront since interaction of light with the grating pattern is wavelength dependent. The diffractive features of SWG layer 1200 may be specifically chosen to selectively filter a multiple-component wavefront as required for a particular application thereof. In the example depicted in FIG. 12, SWG layer 1200 is designed to control wavefront 1102 such that spectral components with wavelength λ_2 , or close thereto, are blocked and spectral components with other wavelengths are transmitted therethrough. More specifically, the phase change induced by SWG layer 1200 causes (i) the spectral component 1104 of wavefront 1102, corresponding to a beam of light with wavelength λ_1 , to be transmitted through output surface 1116 without deflection, and (ii) the spectral component 1106 of wavefront 1102, corresponding to a beam of light with wavelength λ_2 , to be absorbed by the grating. It will be understood that a SWG layer may be designed to filter a multiple-component wavefront in any manner as required for implementing a specific function in an optical device. For example, the SWG layer may filter some spectral components while splitting other spectral components.

In examples, a non-periodical SWG of a SWG layer may be configured such that the SWG layer operates like a lens, which might be configured for, for example, focusing, collimating, or expanding an incident beam. Such a SWG layer operating as a lens may be realized by forming a SWG pattern with a duty cycle symmetrically varying with respect to an axis of symmetry, the axis of symmetry defining an optical axis of the SWG layer. Examples of such SWG layers are illustrated with respect to FIGS. 13A-13B.

FIGS. 13A and 13B illustrate a SWG layer 1300 arranged to be operated as a lens. More specifically, SWG layer 1300 can be operated as a convex lens for focusing incident light. FIG. 13A shows a top plan view of a one-dimensional grating pattern of SWG layer 1300 configured to focus incident light into a focal point 1336 by appropriately tapering the lines of the grating away from the center of SWG-layer 1300; FIG. 13B shows a cross-sectional view of SWG layer 1300 in operation.

SWG layer 1300 includes a non-periodical SWG with a grating pattern represented by annular shaded regions 1302-1305. Each shaded annular region represents a different grating sub-pattern of lines. Enlargements 1308-1311 show that the SWG includes lines tapered in the y-direction with a constant line period spacing p in the x-direction. More specifically, enlargements 1308-1310 are enlargements of the same lines running parallel to dashed-line 1314 in the y-direction. Enlargements 1308-1310 reveal that the line period spacing p remains constant but the width of the lines narrow or taper away from the center of the SWG in the y-direction. Each annular region has the same duty cycle and period. For example, enlargements 1308-1311 reveal portions of annular region 1304 comprising portions of different lines that have substantially the same duty cycle. As a result, each portion of an annular region produces the same approximate phase shift

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in the light transmitted through SWG layer 1300. For example, dashed circle 1316 represents a single phase shift contour in which light transmitted through the SWG layer anywhere along the circle 1316 acquires substantially the same phase ϕ .

As depicted in FIG. 13B, the phase change causes a parallel wavefront 1318, corresponding to a beam of light with wavelength λ directed normal to an input surface 1312 of SWG layer 1300, to be transmitted through an output surface 1322 of SWG layer 1300 as an output wavefront 1318' converging towards focal point 1336.

A SWG layer is not limited to one-dimensional gratings as illustrated with respect to FIGS. 7, 10A-13B. A SWG layer can be configured with a two-dimensional non-periodical SWG so that the SWG layer can be operated to implement a specific wavefront control function or other optical functions such as focusing, expanding, or collimating an incident beam. In examples, a non-periodical SWG is composed of posts rather than lines, the posts being separated by grooves. The duty cycle and period can be varied in the x- and y-directions by varying the post size. In other examples, a non-periodical SWG layer is composed of holes separated by solid portions. The duty cycle and period can be varied in the x- and y-directions by varying the hole size. Such post or holes may be arranged according to a variety of shapes such as circular or rectangular shapes.

Further, SWG layers may be arranged to operate as a lens through a diffractive pattern comprised of concentric rings. More specifically, such SWG layers include concentric rings formed from a dielectric material interleaved by a plurality of gaps separating the plurality of concentric rings. Further, such SWG layers may include a disc formed at, approximately, the center of the lens that is formed from the dielectric material. The disc may have a thickness similar to the thickness of the plurality of concentric rings. The dielectric material layer may include silica. The thickness, gap spacing, ring width, and ring number are selected to determine the optical characteristics (e.g., focal length) associated with the lens.

As illustrated above, a SWG layer can be arranged to implement a particular optical function by appropriately designing a phase change induced to an incident wavefront. There are a number of ways for designing the induced phase change. In an example, for configuring the SWG layer, a transmission profile may be determined using an appropriate computing tool, such as the application "MIT Electromagnetic Equation Propagation" ("MEEP") simulation package to model electromagnetic systems, or COMSOL Multiphysics® which is a finite element analysis and solver software package that can be used to simulate various physics and engineering applications. A determined transmission profile may be used to uniformly adjust geometric parameters of the entire SWG layer in order to produce a particular change in the transmitted wavefront.

Manufacturing Optical Fiber Connector: FIG. 14 illustrates examples of a method 1400 for manufacturing an optical fiber connector. The optical fiber connector is for optically coupling a beam into or out of an optical fiber. In discussing FIG. 14, reference is made to the schematic views in FIGS. 15A and 15B to provide contextual examples. Implementation of method 1400, however, is not limited to those examples. FIG. 15A is a schematic isometric view depicting (i) a ferrule 1500 for a MT connector, and (ii) a SWG assembly 1502 decoupled from ferrule 1500. FIG. 15B is a schematic isometric view of a MT optical connector 1504 including ferrule 1500 with SWG assembly 1502 coupled thereto.

In this example connector 1504 is a three terminal connector. Ferrule 1500 is arranged for receiving three optical fibers

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1506-1508. Further, SWG assembly **1502** includes three optical coupling regions **1510-1513**, each region corresponding to a terminal of connector **1504**. Each coupling region **1510-1513** includes a stack of SWG layers arranged to perform a combination of optical function suitable to couple light from a corresponding optical fiber to a corresponding optical channel (not shown) of connector **1504**, analogously as described above. The coupling regions are disposed at SWG assembly **1502** such that they can be aligned with respective optical fibers at ferrule **1500**. (For example, coupling region **1510** is disposed to be aligned with optical fiber **1506** when SWG assembly **1502** is mounted onto ferrule **1500**.)

Although connector **1504** is illustrated as a MT connector for three terminals, connector **1504** may be adapted to interconnect any number of terminals required for a particular optical application. That is, ferrule **1500** may be adapted to receive any number of optical fibers, and SWG assembly **1502** may include any corresponding number of optical coupling regions. Further, connector **1504** may be for a single optical fiber. The single optical fiber may include a single core, or multiple cores.

At **1402**, SWG assembly **1502** is coupled to ferrule **1500**. At **1404** SWG assembly **1502** is aligned to optically couple optical fibers **1506-1508** to corresponding optical channels (not shown) of connector **1504**. In the illustrated example, coupling **1402** and aligning **1404** are performed quasi-simultaneously. More specifically, ferrule **1500** may include a socket **1514** adapted to receive SWG assembly **1502** such that it is automatically aligned to optical fibers **1506-1508** when mounted onto socket **1514**. That is, socket **1514** may be dimensioned and positioned such that when SWG assembly **1502** is inserted therein, coupling regions **1510-1512** are aligned to corresponding optical fibers **1506-1508**. Additionally to these steps, coupling **1402** may include fixing SWG assembly **1502** to the ferrule. Fixing may include bonding the assembly to the ferrule or activating a fixing device such as a clamp or the like.

Coupling **1402** and aligning **1404** may be performed in a number of different ways. Further, aligning **1404** may be performed without using a socket in the ferrule. For example, SWG assembly **1502** may be brought into contact with a flat surface of ferrule **1500** where optical fibers **1506-1508** end and, subsequently, the SWG assembly may be aligned with optical fiber **1506-1508** using an active alignment system (e.g., using a combination of a fiducial arrangement at the ferrule and a machine vision system).

There are a number of ways of manufacturing a SWG assembly as described herein. For example, a SWG assembly may be manufactured using micro-fabrication techniques such as lithography, imprint processes, layer deposition, or a combination thereof.

In some examples, one or more SWG layers may be formed on a transparent substrate using such micro-fabrication techniques. For example, a first SWG layer may be formed on a side of the substrate. Additional SWG layers may be formed over the first SWG layer by a process combining film deposition and lithography.

In further examples, a first SWG layer may be formed on a first side of the substrate and a second SWG layer may be formed on a second side of the substrate opposite to the first side. Additional SWG layers may be formed over any of the first or second SWG layers.

In other examples, a first SWG layer and the first substrate form part of a first integrated structure; a second SWG layer is formed on a second substrate, the second SWG layer and the second substrate form part of a second integrated structure. To form a SWG assembly as described herein, the first

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integrated structure and the second integrated structure may be bonded to form a single integral device. Further SWG layers may be integrated in the device by bonding of further integrated structures.

In the foregoing description, numerous details are set forth to provide an understanding of the examples disclosed herein. However, it will be understood that the examples may be practiced without these details. While a limited number of examples have been disclosed, numerous modifications and variations therefrom are contemplated. It is intended that the appended claims cover modifications and variations of the illustrated examples. Specifically, it will be understood that the number and arrangement of SWG layers illustrated above are chosen to describe some particular examples. Optical devices are contemplated that include any number and arrangement of SWG layers suitable to implement a particular connectability between optical components. Further, some of the examples herein illustrate beam expansion connectors, however it will be understood that optical connectors contemplated herein are not limited to this type of connectors. Connectors according to examples may implement a variety of functions such as beam separation, beam splitting, filtering of spectral components, beam polarization, or combinations of such optical functionalities within an optical connector.

Claims reciting “a” or “an” with respect to a particular element contemplate incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Further, the terms “include” and “comprise” are used as open-ended transitions.

What is claimed is:

1. An optical device comprising:

an input optical channel and a corresponding output optical channel; and

an assembly of stacked sub-wavelength grating (SWG) layers aligned to optically couple the input optical channel to the output optical channel,

wherein the optical device is a multiple terminal optical device including a plurality of input optical channels and a plurality of corresponding output optical channels, the SWG assembly being aligned to optically couple the plurality of input optical channels to the plurality of output optical channels.

2. The device of claim 1, wherein the device is a multicore optical fiber optical connector.

3. The device of claim 1, wherein the SWG assembly is arranged to deflect beams emitted from the input optical channels to separate the optical beams.

4. The device of claim 1, wherein the SWG assembly includes a SWG sub-assembly to collimate a beam emitted from the input optical channel.

5. The device of claim 1, wherein the SWG assembly includes a SWG sub-assembly to deflect a beam emitted from the input optical channel.

6. The device of claim 1, wherein the device is an expanded beam connector.

7. The device of claim 1, wherein the SWG assembly includes a transparent solid layer separating stacked SWG layers.

8. The device of claim 1, wherein a SWG grating layer of the SWG assembly includes a non-periodic SWG layer arranged to shape or control a beam from the input optical channel.

9. A multicore optical fiber connector comprising:

a ferrule for receiving a multicore optical fiber;

a plurality of optical channels; and

a SWG assembly including a plurality of stacked SWG grating layers, each of the SWG layers including a non-

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periodic SWG layer, the SWG assembly being arranged to optically couple cores of the multicore optical fiber to channels of the plurality of optical channels.

10. The connector of claim 9, wherein the SWG assembly includes

- a SWG expanding sub-assembly to individually expand beams emitted from the plurality of cores, and
- a SWG collimating sub-assembly to individually collimate beams expanded at the SWG expanding sub-assembly.

11. The connector of claim 9, wherein the SWG assembly includes

- a SWG collimating sub-assembly to individually collimate beams emitted from the plurality of cores,
- a first SWG deflection sub-assembly to individually deflect beams collimated at the SWG collimating sub-assembly so as to separate the collimated beams, and
- a second SWG deflection sub-assembly to further deflect the beams deflected at the first SWG deflection sub-assembly towards the plurality of optical channels.

12. The connector of claim 9, wherein the connector is adapted to optically couple light emitted from a multicore optical fiber end with an angled facet.

13. A method of manufacturing an optical fiber connector for optically coupling a beam into or out of an optical fiber, the method comprising:

- coupling an assembly of stacked SWG layers to a ferrule, the ferrule being to receive an optical fiber;
- aligning the SWG assembly to optically couple the optical fiber to an optical channel of the connector through the SWG assembly,

wherein the connector is for individually coupling a plurality of beams into or out cores of a multicore optical fiber, the ferrule being to receive the multicore optical fiber.

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14. An optical device comprising:

a first element distinct; and a second element, wherein the first element is distinct from the second element,

wherein the first element includes an input optical channel, and the second element includes a corresponding output optical channel,

wherein the first element and the second element include mating elements to couple the first element to the second element,

wherein the first element further includes an assembly of stacked sub-wavelength grating (SWG) layers aligned to optically couple the input optical channel to the output optical channel when the first element is coupled to the second element.

15. The device of claim 14, wherein the SWG assembly includes a SWG sub-assembly to collimate a beam emitted from the input optical channel.

16. The device of claim 14, wherein the SWG assembly includes a SWG sub-assembly to deflect a beam emitted from the input optical channel.

17. The device of claim 14, wherein the device is an expanded beam connector.

18. The device of claim 14, wherein the SWG assembly includes a transparent solid layer separating stacked SWG layers.

19. The device of claim 14, wherein a SWG grating layer of the SWG assembly includes a non-periodic SWG layer arranged to shape or control a beam from the input optical channel.

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